Development and Demonstration of Medium- and Heavy-Duty PHEV Work Trucks

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Organization: Odyne Systems, LLC

Date: June 20, 2018

Project ID: elt094

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Project Overview

Timeline:

- Start Date: January 19, 2017
- Completion Date: April 30, 2020
- Percent Complete: 30%

Barriers

- Fuel efficiency of Medium/Heavy-duty work trucks
- Integration of Driving and Jobsite electrification of Medium/Heavy-duty work trucks
- Return-on-investment of electrified Medium/Heavy-Duty work trucks

Budget

- Total project funding: $6,955,281
  - DOE Share: $2,149,644
  - FFRDC Share: $ 782,549
  - Contractor Share: $4,023,088
- FY17 DOE Funding: $ 458,938
- FY18 DOE Funding: $1,298,701

Project Partners

- Odyne Systems – Project Lead
- Freightliner Trucks
- Allison Transmission
- Ricardo Engineering
- Duke Energy
- Sempra Energy
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- South Coast Air Quality Management

Relevance / Objectives

- Overall Objectives
  - To develop and demonstrate an advanced Plug-in Hybrid Electric (PHEV) Medium-Heavy Duty Work Truck
    - With greater than 50% reduction in fuel consumption when compared to a conventional diesel vehicle baseline
    - With a targeted return on investment of ≤5 years.

- 3 Phases of project
  - Period 1 (Current Phase): System Design and Analysis
  - Period 2 (FY18 end, FY19): Prototype Refinement and Verification
  - Period 3 (FY19 end, FY20): 10 Vehicle Customer Deployment and Demonstration
    - 5 Vehicles to be deployed in the South Coast Air Quality Management District

- 3 Focus areas
  - Optimization of Powertrain and Full Vehicle Energy Use
  - Battery System Sourcing and Development
  - Chassis/Vehicle/System Development and Integration

Any proposed future work is subject to change based on funding levels

Relevance / Objectives

- Objectives this period
  - Develop baseline data and tools
    - Work Truck Driving and Stationary Duty Cycles from Telematics Data
    - Full-year combined duty cycle Fuel-use Model
    - Baseline Dynamometer Testing
    - Hybrid Powertrain Simulation correlated to baseline dynamometer testing
  - Identify and evaluate solution set
    - Controls: PHEV Driving algorithms and optimization
    - Controls: Full day optimization
    - Components: Cost Reduced modular battery system
    - Components: Cost Reduced power electronics, drivetrain, and system
    - Integration: Vehicle and work equipment design and controls
- Relevance
  - Lower system cost and increased fuel savings lead to improved ROI for the fleet customer, which will lower the barriers to entry and increase adaptation

Milestones

Milestone	Date	Status 4/20/18
Budget Period 1		
Duty Cycle and System Analysis	July, 2017	Complete
Baseline Dynomometer Testing	September, 2017	Complete
Powertrain Simulation Correlation	April, 2018	Complete
Battery System Selection	May, 2018	On Track
Powertrain Controls Strategy	June, 2018	On Track
Full Year Fuel Savings Analysis	June, 2018	On Track
Prototype Design Freeze (Go-No Go)	June, 2018	On Track
Budget Period 2		
Prototype Vehicle Functional Validation	December, 2018	On Track
Hardware in the Loop (HIL) Powertrain Verification	March, 2019	On Track
Prototype Vehicle Performance Validation (Go-No-Go)	May, 2019	On Track
Evaluation Fleet Build and Delivery	August, 2019	On Track

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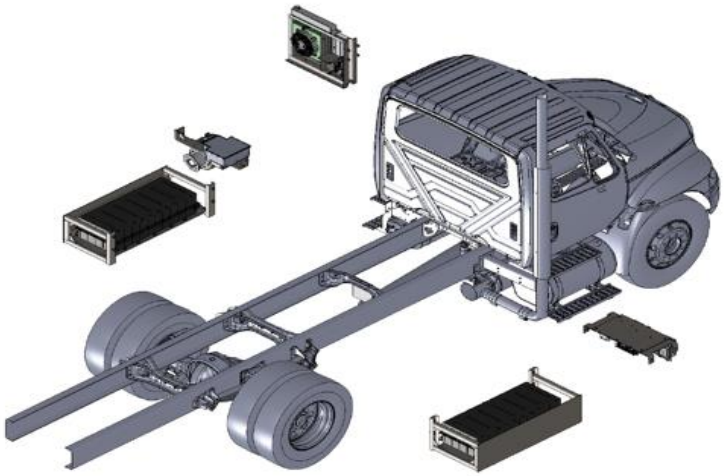
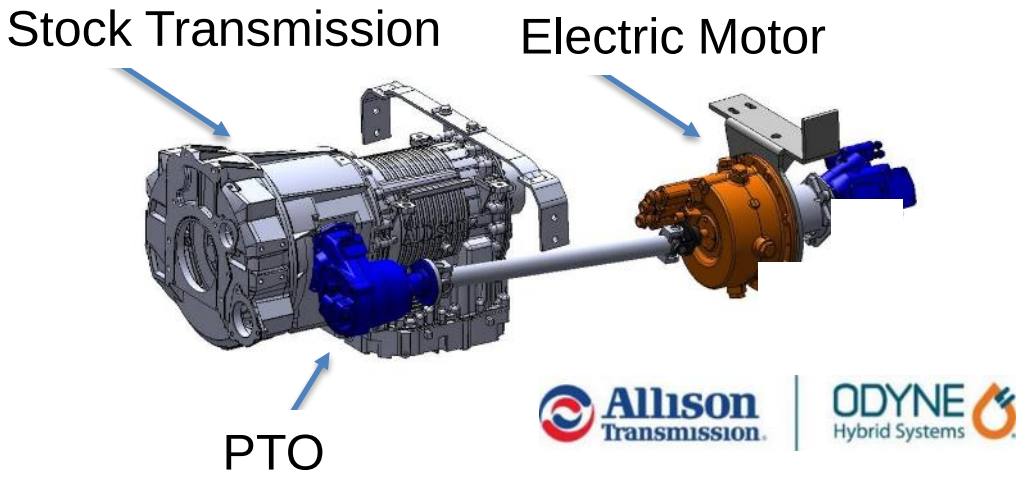
Approach:
Base System

Plug-in hybrid propulsion
+ work site idle reduction





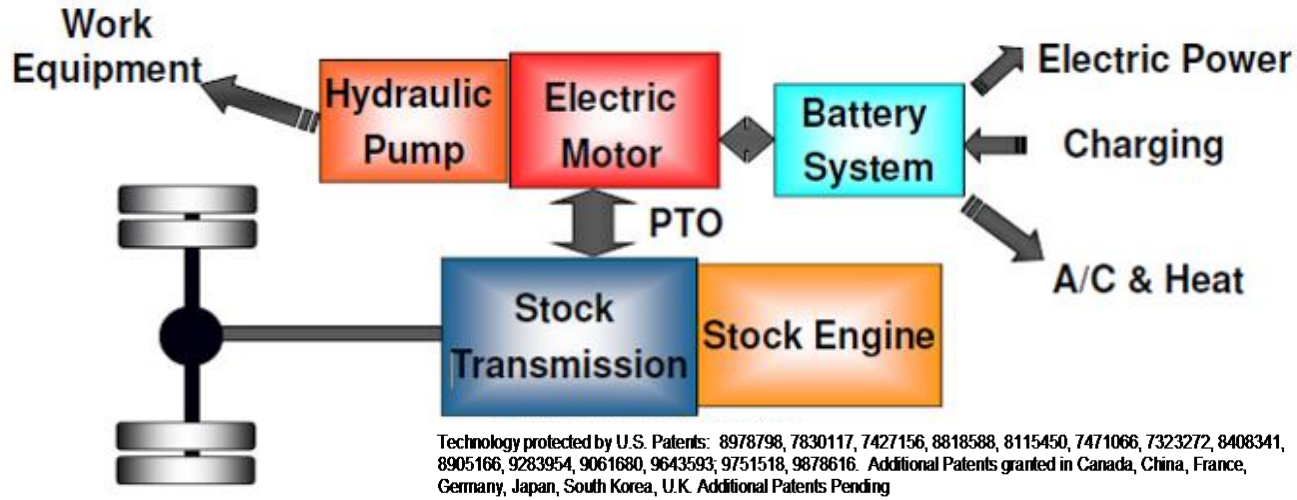
Flexible

Modular Design applied to OEM Chassis
Multiple OEM and Application platforms
- Same base hybrid system

Minimally Intrusive

Hybrid Power through existing PTO port
No Changes to Base Powertrain
Allison Approved – Retains Powertrain Warranty

Approach:
Base System



Bolts onto transmission, very robust and flexible design

- Hybrid propulsion through Power Take-off (PTO) connection with transmission
  - Launch assist and regenerative braking: more power, better driving efficiency
- Jobsite functions supported by Battery/Electric Motor:
  - Powers up to 60 kW of Hydraulic/ Pneumatic equipment
  - Provides up to 15kW of 120/240 VAC exportable power, 4 kW of 12VDC, Electric A/C
  - Field recharge via Diesel Engine if required – No interruption in jobsite function

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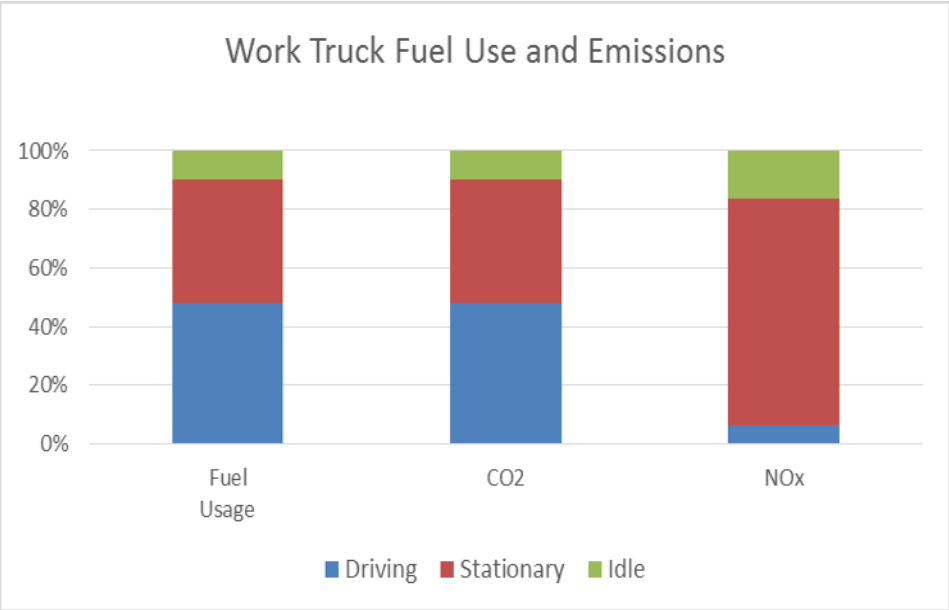
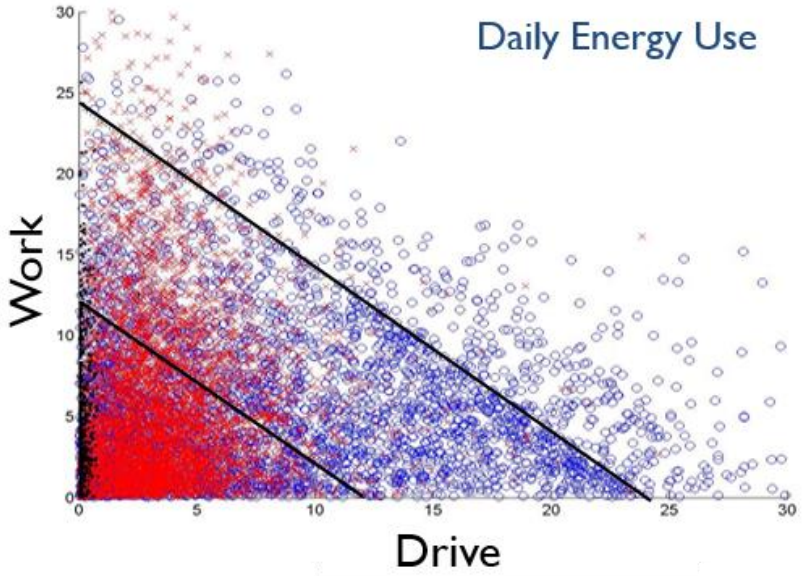
Approach:
Optimization Background

- Work Trucks are unique:
  - Up to 50% of fuel is used performing stationary functions
  - Every Day is different – some are work heavy, some are drive heavy
  - Final configuration is dictated by fleet customers and final stage (equipment) manufacturers - built on multiple OEM platforms – every truck is unique
- Odyne Solution: Modular PHEV/Jobsite Electrification system, however:
  - Fuel Savings could increased with better Driving / Worksite energy balance
  - Too many vehicles return to base with excess battery remaining





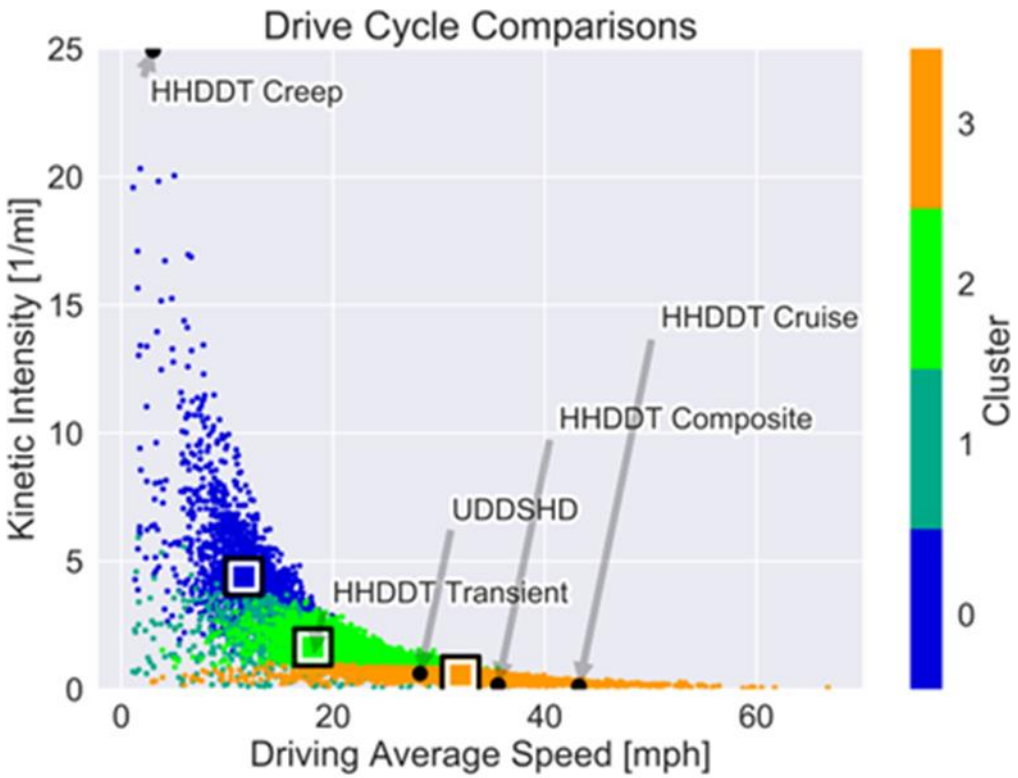
Approach: Technical

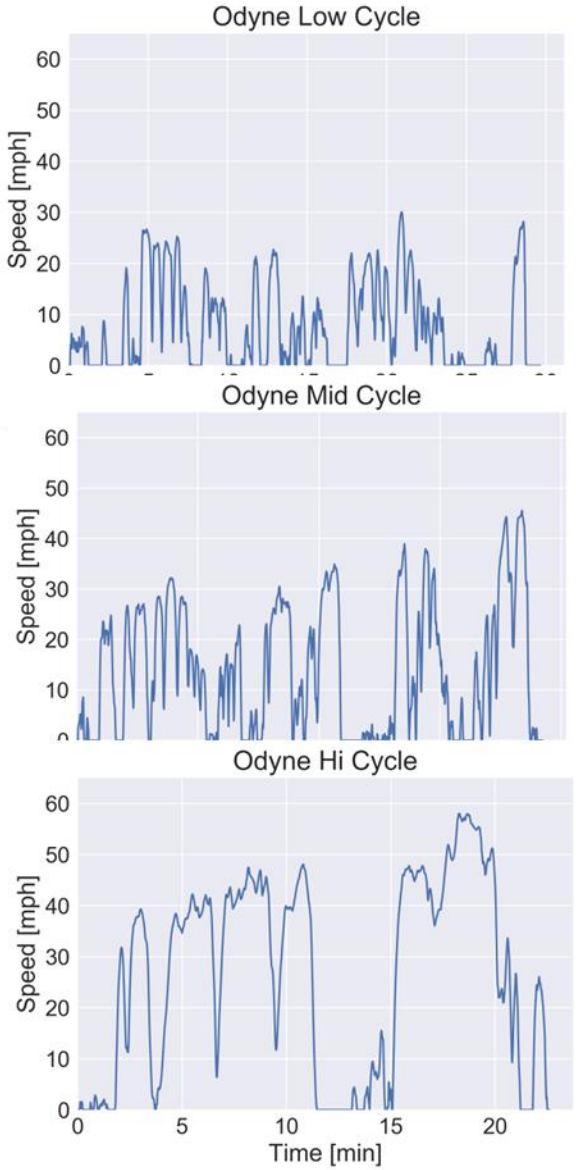
- Optimize PTO based hybrid system based on real world work truck full-day duty cycles derived from fleet telematics
  - Use Simulation to define optimized use of electric energy while driving
  - Develop work truck hybrid control to optimize driving/stationary energy use
    - Individual vehicle Learning Algorithms
    - Driver/Fleet input – single day optimization
    - Integration of hybrid boost, balance and charge modes

- Reduce Cost through functional integration and advancements in Lithium Ion Battery, Power Electronics, and up-integration into final vehicle
  - Develop modular Lithium-ion battery based on high volume cells/modules
  - Combine power electronics functions into single modules
  - Improve the integration with OEM Chassis and Final Stage Manufacturer equipment

Technical Accomplishments
Driving Duty Cycle (Milestone 1: July 2017)

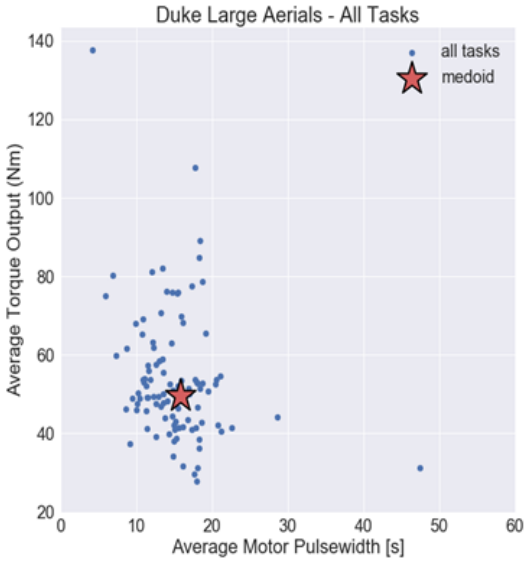
- 119 Vehicle Odyne Telematics data transferred to NREL
- Data sorted/ filtered: 26,539 Vehicle Days Processed
  - Processed through NREL Drive-Cycle Rapid Investigation, Visualization, and Evaluation (DRIVE) tool
  - 3 new drive cycles created for test and simulation

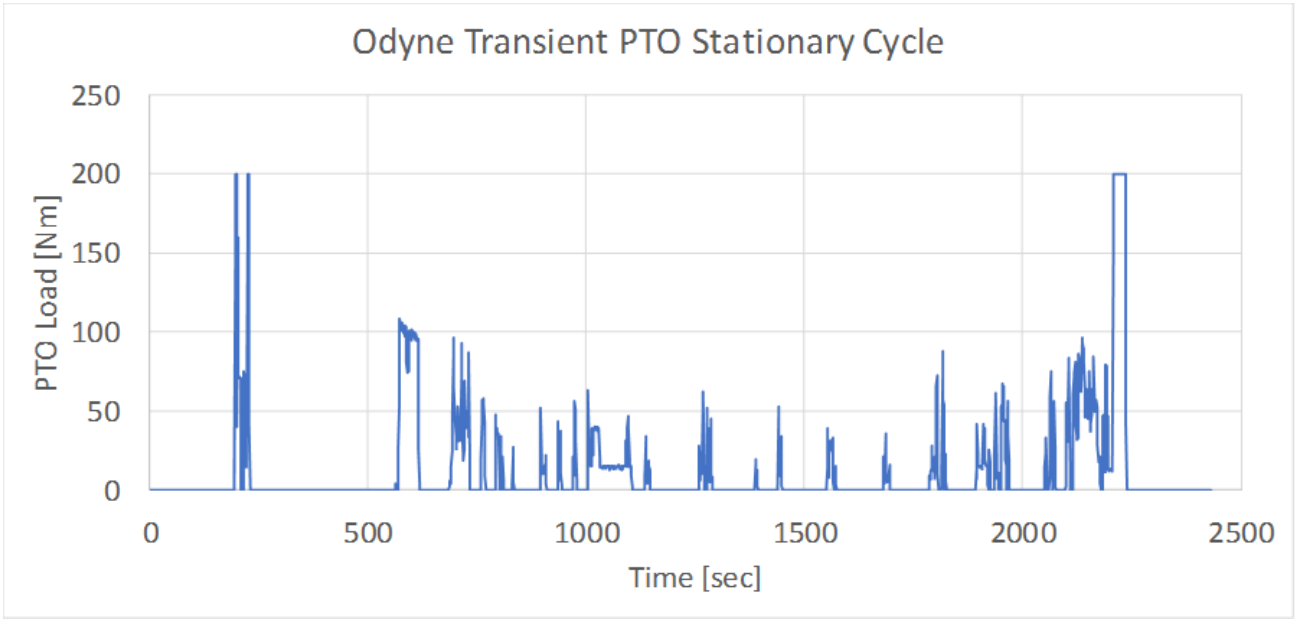


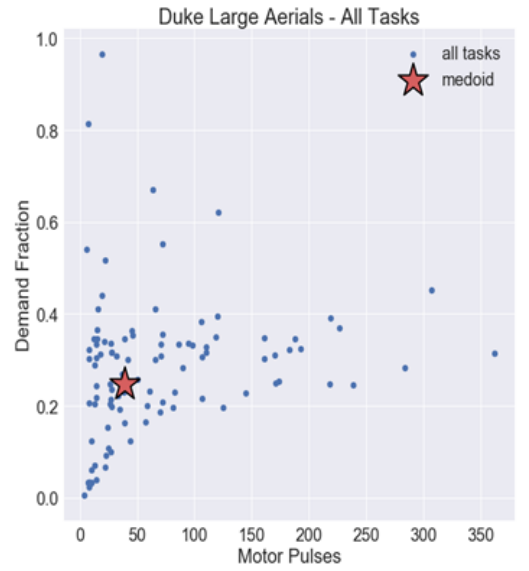


Technical Accomplishments
Stationary Duty Cycle (Milestone 1: July 2017)

- NREL adapted methods utilized in creating drive cycles to develop a stationary duty-cycle
  - New Stationary Jobsite metrics were developed
  - Telematics data grouped, analyzed
- A transient PTO Stationary duty cycle was created for dynamometer testing and vehicle full-day simulation

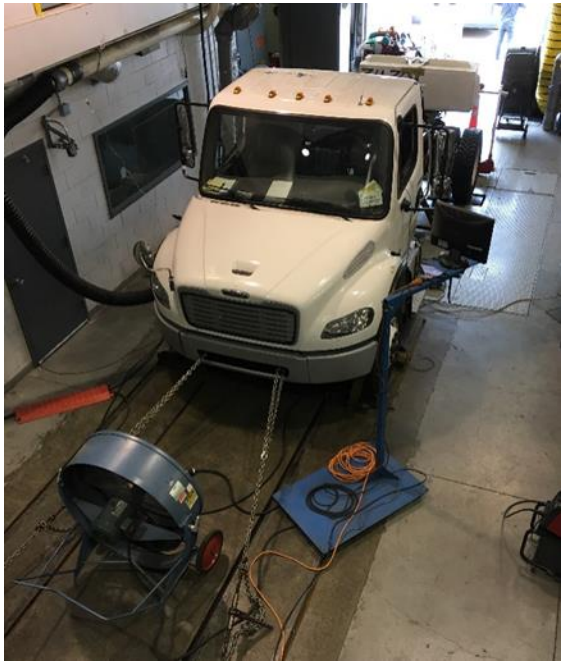






Technical Accomplishments
Dynamometer Testing (Milestone 2:September 2017)

- A 2017 Freightliner-Odyne Hybrid Work truck Chassis was tested at the NREL ReFUEL Dynamometer test facility
  - 3 NREL-Odyne Drive Cycles
  - 2 Standard Drive Cycles
  - Transient PTO Stationary cycle
  - PTO Stationary Fuel Mapping
  - Stationary Battery Recharge Cycle



- Data was delivered to Odyne and Oak Ridge National Lab to begin model correlation and drive optimization

Technical Accomplishments
Baseline Results: Dynamometer Testing

- Baseline Driving results consistent with past experience
  - Result of production low speed / mild drive calibration

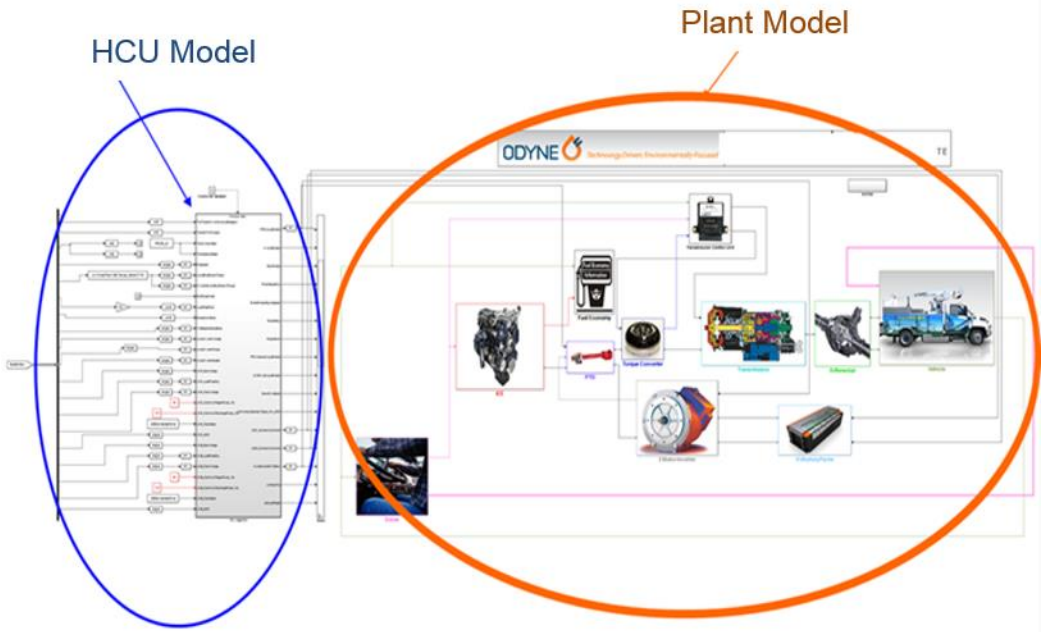
Odyne-NREL Baseline Drive Cycle Testing		Fuel economy MPG	Hybrid Improvement %	Battery Use kWh/mi
UDDS	Conventional	6.19		
	Hybrid	6.31	1.99%	0.02
ODYNE High	Conventional	7.53		
	Hybrid	7.53	0.05%	-0.02
ODYNE Medium	Conventional	6.04		
	Hybrid	6.30	4.26%	0.16
ODYNE Low	Conventional	4.22		
	Hybrid	4.58	8.47%	0.47
HHDDT Transient	Conventional	5.86		
	Hybrid	6.24	6.57%	0.21

- NREL Preliminary Calculations:
  - ePTO is 5 times more efficient for fuel use and CO2 and nearly 10 times better for NOx – even when deriving energy from diesel field recharge

PTO shaft work specific results comparison			
	NOx	CO2	Fuel Use
	g/kW-hr	g/kW-hr	g/kW-hr
Calculated equivalent electrical PTO	**3.34**	**1815.21**	**549.59**
Tested conventional PTO	**32.61**	**8483.42**	**2827.03**

Technical Accomplishments
Simulation Correlation (Milestone 3: April 2018)

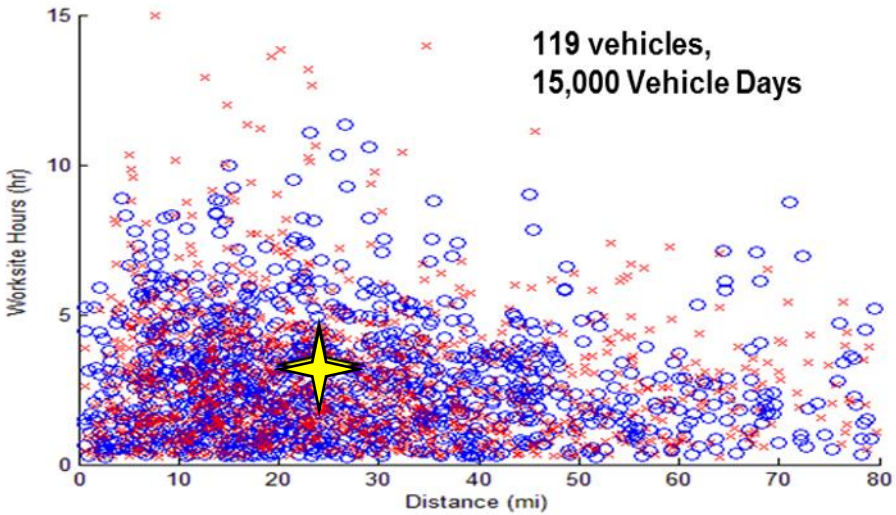
- Oak Ridge National Lab, and Odyne prepared a Simulink Model incorporating the vehicle and hybrid system model and the current hybrid controls
- NREL Dynamometer Data was used to begin model correlation.
- After many iterations and refinements of the plant model, >90% correlation was achieved across all drive duty cycles
- Next step: Use simulation model for optimization and hybrid control improvements



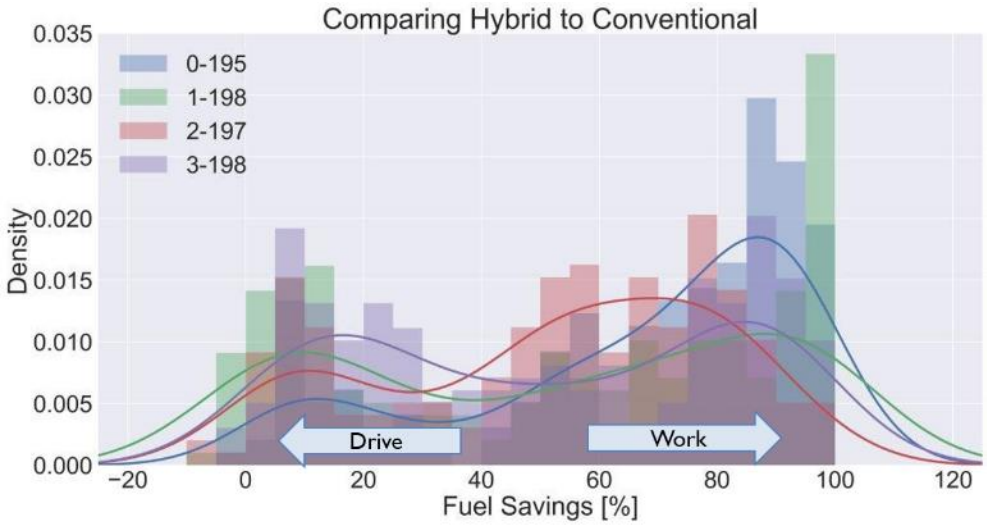
Odyne M2 ISB Correlation Results		UDDS			$HHDDT_{trans}$			NREL Low			NREL Med			NREL High		
Metric	Units	Dyno	Model	% Corr	Dyno	Model	% Corr	Dyno	Model	% Corr	Dyno	Model	% Corr	Dyno	Model	% Corr
Avg. Speed	MPH	18.55	18.59	100%	15.16	14.94	101%	7.55	7.45	101%	13.76	13.61	101%	25.98	25.94	100%
Fuel Use - Conventional	Gal	0.92	0.99	91%	0.49	0.50	98%	0.91	0.92	99%	1.52	1.60	95%	1.35	1.47	91%
Fuel Use - Hybrid Mild	Gal	0.89	0.93	95%	0.46	0.47	98%	0.83	0.80	103%	1.53	1.45	105%	1.35	1.43	94%

Technical Progress
Full Year Fuel-use Model (Prep,Milestone 6: June 2018)

- Prior telematics data analysis had demonstrated that each day can be different for a utility work truck
  - Average Day: 26 miles, 4.2 Jobsite hours



- NREL developed a full year model to simulate the effect of daily variation
  - High fuel savings on work oriented days
  - Modest savings on drive oriented days



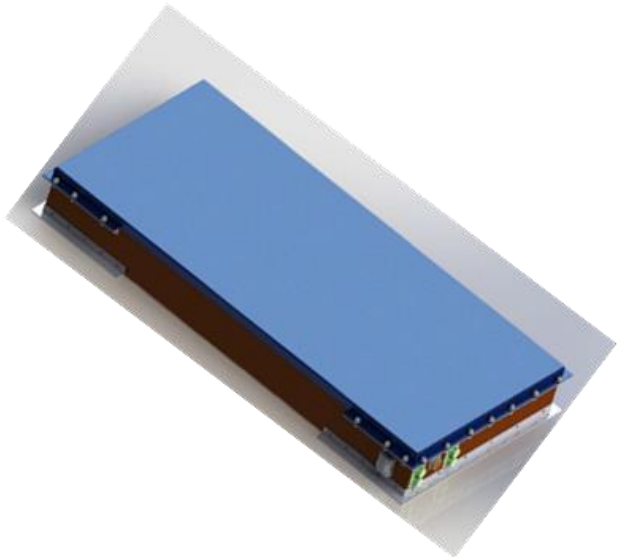
- Next steps: Use simulation model to evaluate the effects of learning algorithms and driver/fleet input

NREL Preliminary Results for illustration only

Technical Progress
Battery Systems (Milestone 4: May 2018)

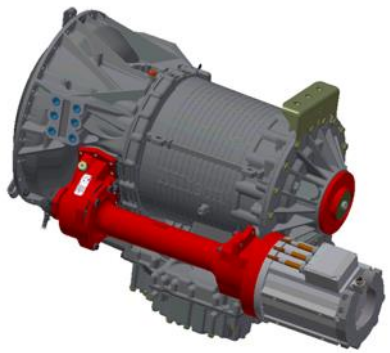
- Battery Systems
  - Requirements and targets created around 350V, 10-16kWh base system
  - Supplier Search was conducted by Odyne, AVL, Ricardo Strategic Consulting
    - Standard Packs
    - Configurable Solutions
  - OEM, Tier 1 and Mid-Level Pack Producers contacted formally (RFQ) and informally

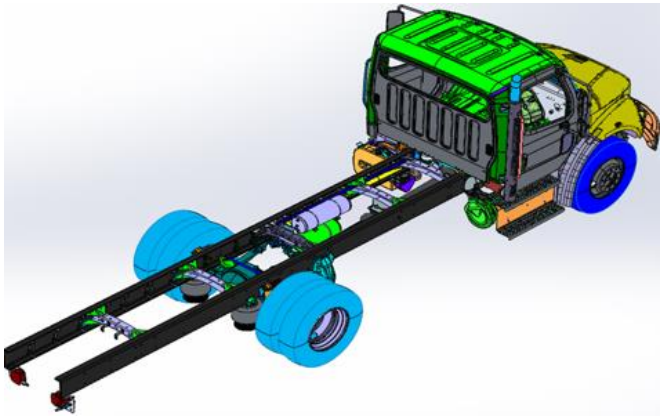
- Status (4/20/18)
  - 2 solutions under evaluation /design development
  - 4 additional solutions under initial technical / commercial investigation

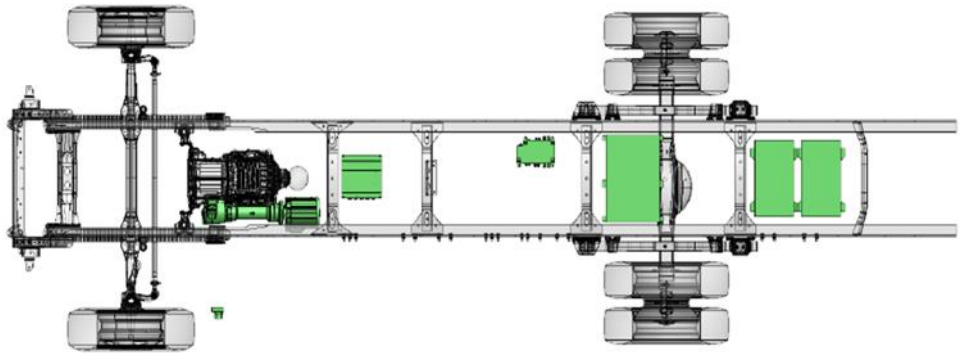


Technical Progress
Remaining System and Vehicle Design

- New Components
  - 15 kW Bi-Directional Charger,4 kW DC-DC
  - Integrated PTO/Traction Motor Developed
  - Remaining Power Electronics /Major Components selected except:
    - Integrated A/C concept: in design-development
    - Cooling System: Awaiting Battery Decision
- Test truck & System Layout
  - 2017 Freightliner M2 106 Test Chassis completed
  - Layout in process – awaiting final battery







Responses to Previous Year Reviewer Comments

- Not Reviewed Last Year

Collaborators /Team

Organization	Function
National Renewable Energy Laboratory	• Telematics Duty Cycle Analysis • Fuel & Emissions Dynamometer Testing • Full Year Fuel Use Modeling
Oak Ridge National Laboratory	• Powertrain Simulation, Energy use optimization • Hardware-in-Loop (HIL) Powertrain Testing
Freightliner Trucks	• Chassis System Integration assistance, Vehicle models • Investigating commercialization codes for Odyne System • Truck Supplier for Prototype truck, Demo Fleet
Allison Transmission	• Powertrain and transmission optimization support • Transmission Control System integration
AVL	• Battery System Sourcing evaluation
Ricardo Stratigic Sourcing	• Battery System Sourcing Proposal lead
Sempra & Duke Energy	• Provide 5 vehicles each for demo fleet • Participate in demo evaluation and feedback
South Coast Air Quality Management District	• Project cost share

Remaining Challenges and Barriers

- Period 1: Design and System Development:
  - Evaluate proposed driving improvements on System Simulation,
    - Identify the combination that show capability to achieve up to 50% improvement in driving fuel economy
  - Select 1 or 2 system battery suppliers for development into Period 2
    - Each potential supplier has trade-offs to be considered: Cost, size, technical targets
  - Incorporate final battery into prototype system physical and functional design
    - Layout, Controls, Cooling System, Wiring
  - Identify means to optimize full day work truck energy efficiency through learning algorithms and driver/fleet input

Proposed Future Research

- Period 2: Prototype Build, Refinement and Verification:
  - Install fully functional Hybrid/Diesel powertrain on Oak Ridge HIL
    - Correlate to model
    - Verify up to 50% improvement in driving fuel efficiency
    - Refine Driving algorithms and improve where needed
  - Build and verify functionality of prototype test unit
    - Functional performance of driving, stationary, controls and subsystems
    - Dynamometer testing of Drive and Stationary fuel savings
  - Incorporate full day optimization
    - Strategies developed and incorporated into vehicle and code
    - Simulated effectiveness of full day strategies using new Dynamometer results
  - Build and Deploy Demonstration and Evaluation Fleet (10 Vehicles)
    - Work with Customer to specify and order vehicles
    - Work with OEM and FSM to design, build and deliver vehicles

Any proposed future work is subject to change based on funding levels

Summary

- Odyne and it's project partners are working towards greater acceptance, improved fuel savings, and increased ROI of the Plug-in Hybrid/Jobsite Electrification system for Medium- Heavy-Duty Work Truck through:
  - Increased Driving Fuel Economy
  - Algorithms and/or inputs to manage the drive / work energy balance
  - Improved Full Year Fuel Savings
  - Reduced system cost
- Initial advancements have been made in the areas of:
  - Development of driving and stationary duty cycles for the work truck
  - Development of system model for optimization
  - Development of the system components and vehicle integration
- Next Period Deliverables:
  - Completed Work Truck Design
  - Demonstration of up to 50% improvement in Driving Fuel Economy
  - Analytical Demonstration of 50% reduction in Work Truck fuel use

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Thank You

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